COMMONWEALTH OF VIRGINIA
DEPARTMENT OF MINES, MINERALS AND ENERGY
DIVISION OF MINERAL RESOURCES

Application of Geostatistical Methods in 3-D Modeling of Coal Resources, Buchanan County, Virginia

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APPLICATION OF GEOSTATISTICAL METHODS IN 3-D MODELING OF COAL RESOURCES, BUCHANAN COUNTY, VIRGINIA

ABSTRACT

Recent compilations of coal mine maps, core hole logs, and geologic maps of the Southwest Virginia Coalfield have enabled the creation of a new three-dimensional model of the coal-bearing section in Buchanan County, Virginia. This model is composed of 12 layers, each representing a mined coal bed with its respective thickness and elevation data and mined out areas. Over 1,500 georeferenced coal mine maps and geologic maps of the area have yielded close to 150,000 elevation and thickness data points that were used in the generation of coal bed surfaces. The coal bed surfaces for this model were generated using geostatistical methods enabling error and confidence levels to be established for any location. The high level of detail and spatial accuracy in this model exceeds previous attempts to generate a regional integration of coalfield data and permit a better understanding of the local stratigraphy. Application of this model will not only improve estimates of the remaining coal resources, but will have the added benefit of enhancing mine safety.

INTRODUCTION

Coal is Virginia's most valuable mineral resource. Virginia currently ranks 10th in the nation in coal production, having produced approximately 30 million short tons in 2003. The Southwest Virginia Coalfield is presently the sole source for the State's coal production (Figures 1 and 2). It includes of an area of approximately 1520 square miles within seven counties: Buchanan, Dickenson, Lee, Russell, Scott, Tazewell, and Wise. Estimates of the number of mines in the Southwest Virginia coalfield range between 12,000 and 14,000. Buchanan County, along with Dickenson and Wise counties, account for 85 percent of the coal produced in Virginia.

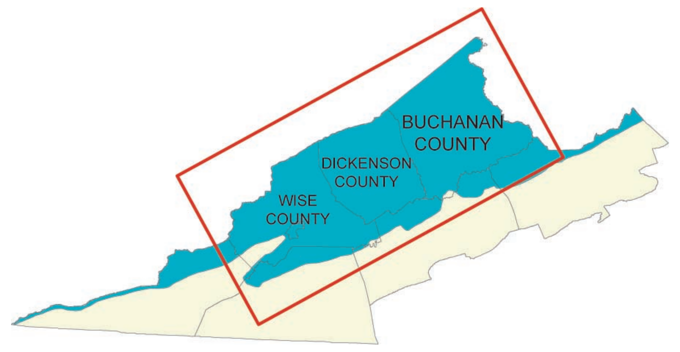


Figure 1. The extent of the Southwest Virginia Coalfield (blue). The red box encompasses the top three coal producing counties of the Coalfield (Buchanan, Dickenson, and Wise).

STRATIGRAPHY

This report focuses on the Splash Dam coal bed, one of the thickest and most mined above-drainage coal beds (Figure 3). The Splash Dam coal bed is commonly considered a coal zone consisting of one to five separate coal beds in Buchanan County. This coal zone is approximately 15 feet thick in the northwest portion of the Harman quadrangle and increases to approximately 50 feet thick in the eastern portion of the quadrangle. The zone is interbedded with sandstone, shale, and/or siltstone. A measurement of 100 coal sections in the Harman quadrangle yielded an average coal bed thickness of 4.6 feet (55.2 inches) (Henika, 1989).

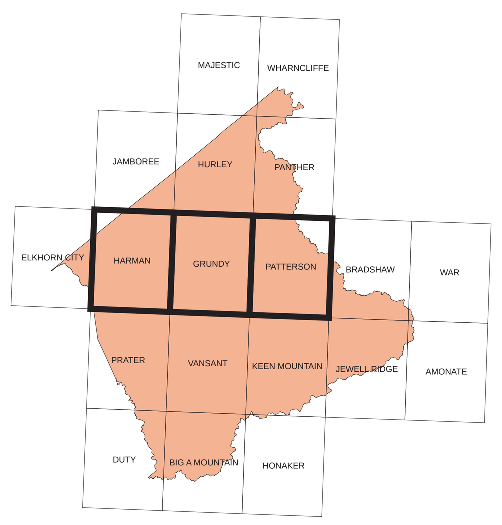


Figure 2. Location of the Harman, Grundy, and Patterson quadrangles in Buchanan County.

COAL POINT COLLECTION METHODS

The Division of Mineral Resources developed the Coal Point program as a quick and easy method to capture thickness and/or elevation information from mine maps. Coal Point is a stand-alone Visual Basic program that displays a form with text boxes for data input, then inserts an attributed symbol as a block into AutoCAD (Figure 4). The attributes of the symbol are derived from the text boxes on the data entry form. These attributes are associated with the location of the symbol and can be extracted with point coordinates.

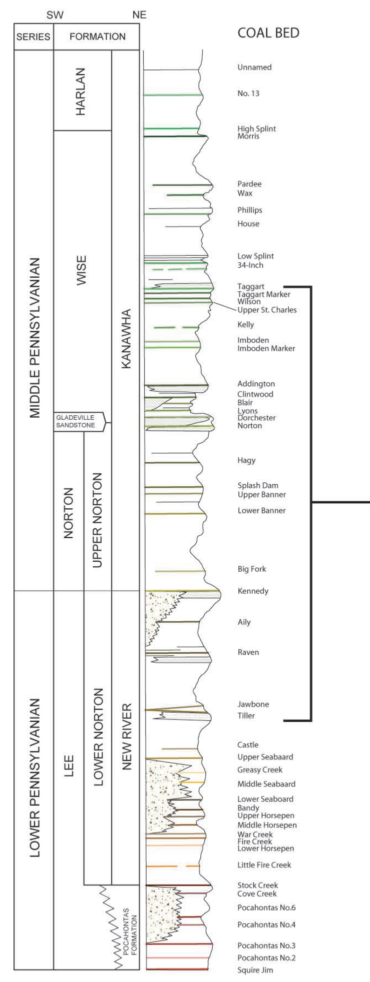
Information stored as attributes are a unique identifier, the type of point (i.e., core data or mine point), total thickness of the coal zone, total thickness of the coal, number of coal intervals, the total height of the mine and the reference map.

These attributes are stored in the AutoCAD drawing along with coordinates and is extracted to create isopach maps, shapefiles, contour maps, statistics, tables and other data displays. Coal Point provides a worksheet to allow many different components to be recorded quickly.

MAP SOURCES

Mine maps used for this project range from computer-drafted maps with abundant thickness and elevation information to hand-drafted maps with little more than the mine outline. Mine maps have been collected from the Department of Mines, Minerals and Energy permitting data, mining companies, enforcement agencies, individuals, libraries, and museums. The dates of these maps range from 1907 to the present.

The 1997 computer-drafted mine map in Figure 5 is a typical example of the better quality maps used for this project. It includes elevation information in the form of structural contours and surveyed elevation benchmarks throughout the mine. Thickness information is also captured from maps like this one in the form of written descriptions of the coal bed (Figure 5). Maps such as this one are used to capture as much information as possible about a mine, such as roof falls, flooding in the mine, nearby gas wells, and thickness information.



REGIONAL COAL EXTENT	BUCHANAN COUNTY MAP UNIT
Taggart	Lower Cedar Grove
Taggart Marker	*NOT MAPPED*
Wilson	Alma; *NOT MAPPED*
Upper St. Charles	*NOT MAPPED*
Kelly	Little Alma
Imboden	Campbell Creek
Imboden Marker	*NOT MAPPED*
Addington	Addington; *NOT MAPPED*
Clintwood	Clintwood
Blair	*NOT MAPPED*
Lyons	Lyons
Dorchester	Dorchester
Norton	Norton
Hagy	Hagy
Splash Dam	Splash Dam
Upper Banner	Upper Banner
Lower Banner	Lower Banner; *NOT MAPPED*
Big Fork	*NOT MAPPED*
Kennedy	Kennedy
Raven	Raven
Jawbone	Jawbone
Tiller	Tiller

Figure 3. Generalized stratigraphic column showing the sequence of Pennsylvanian formations in the Southwest Virginia Coalfield of the Appalachian Plateau. To the right of the column is a table that lists the coals found in Buchanan County and their corresponding regional extent name. The column in the table entitled Buchanan County Map Unit lists the local coal bed names as well as coal bed names from previous mapping. These Buchanan County coals have been correlated to the regional stratigraphic names.

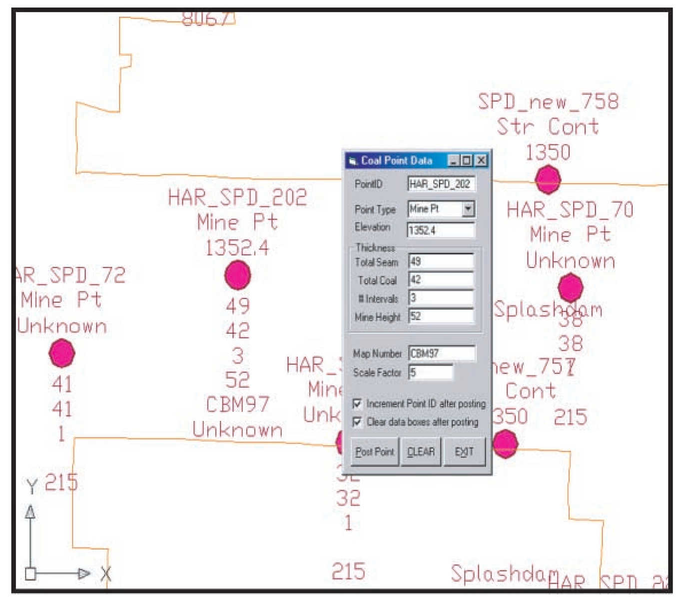


Figure 4. Screen shot of Coal Points and the Coal Point program being used in AutoCAD.

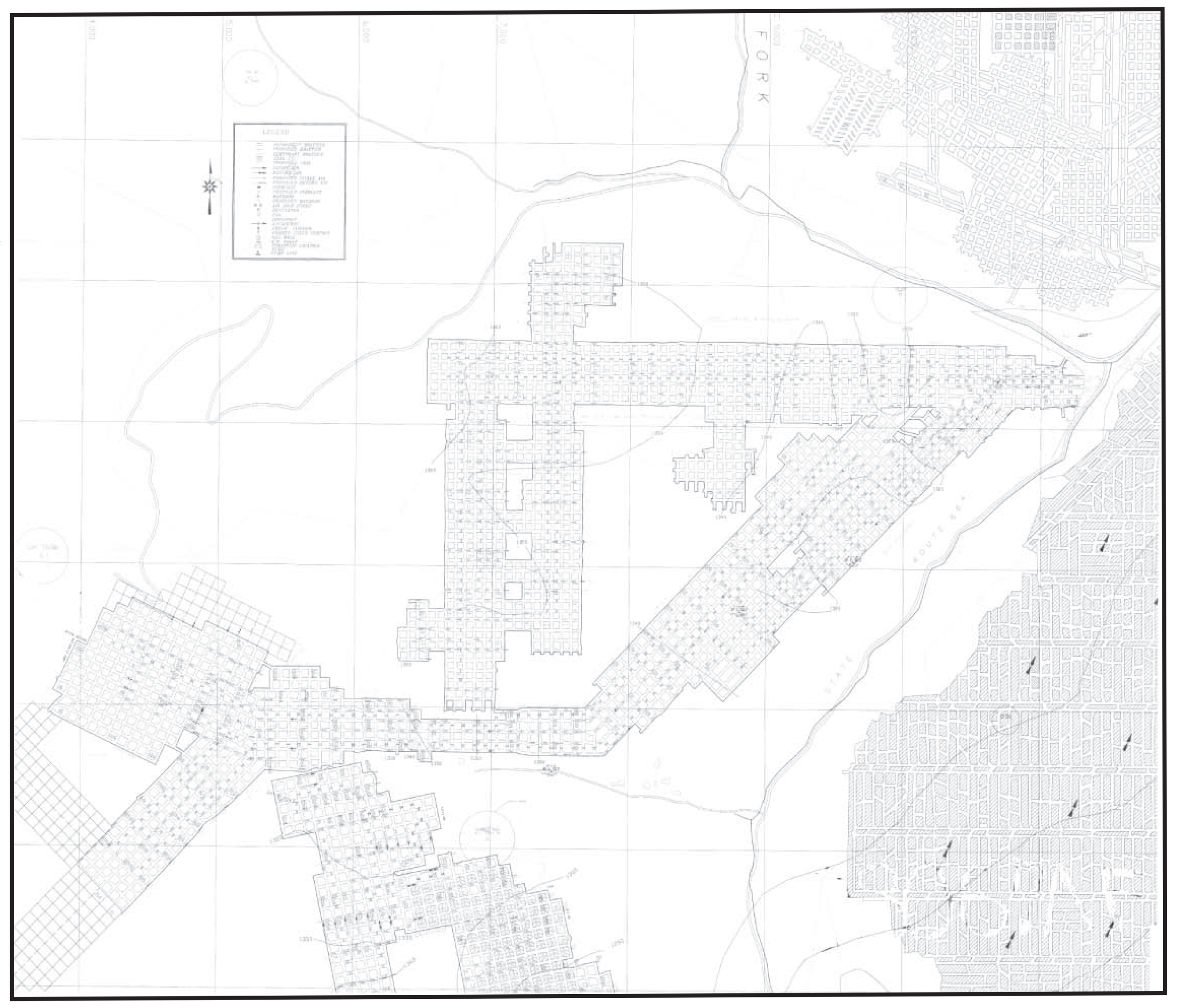


Figure 5. Example of a mine map of the Splash Dam coal bed in the Harman quadrangle .

GEOSTATISTICS

The creation of accurate three-dimensional models of coal beds with an associated, calculated error was a high priority of this project. To create reliable coal surfaces, we used Surfer 8, a contouring and surface mapping program, which allows for variogram modeling and application of kriging theory to the elevation data collected (Figure 6).

Kriging is a geostatistical gridding method for constructing a minimum-error-variance linear estimate at a location where the true value is unknown. This method produces accurate maps from irregularly spaced data, such as coal bed elevation points derived from underground mines. Kriging attempts to express trends suggested in the data, so that, for example, high points might be connected along a ridge rather than isolated by bull's-eye type contours. Kriging is a very flexible gridding method that can be custom-fit to any data set by specifying the appropriate variogram model. It incorporates anisotropy and underlying trends in an efficient and natural manner.

When computing the interpolation weights, the kriging algorithm considers the inherent length scale of the data. For example, the topography in the Virginia Coastal Plain varies much more slowly in space than does the topography in southwestern Virginia. Consider two observed elevations separated by 5 miles. In the Coastal Plain, it would be reasonable to assume a linear variation between these two observations, while in southwestern Virginia such an assumed linear variation would be unrealistic. The algorithm adjusts the interpolation weights accordingly.

Natural phenomena often exhibit preferred orientations. For example, coal beds in southwestern Virginia are rarely horizontal, but instead have a slight dip. Therefore, when interpolating at a point, an observation 100 meters away but in a direction parallel to the strike of the bed is more likely to be similar to the value at the interpolation point than is an equidistant observation in a direction perpendicular to the strike of the bed. When computing the interpolation weights, the algorithm incorporates this natural anisotropy.

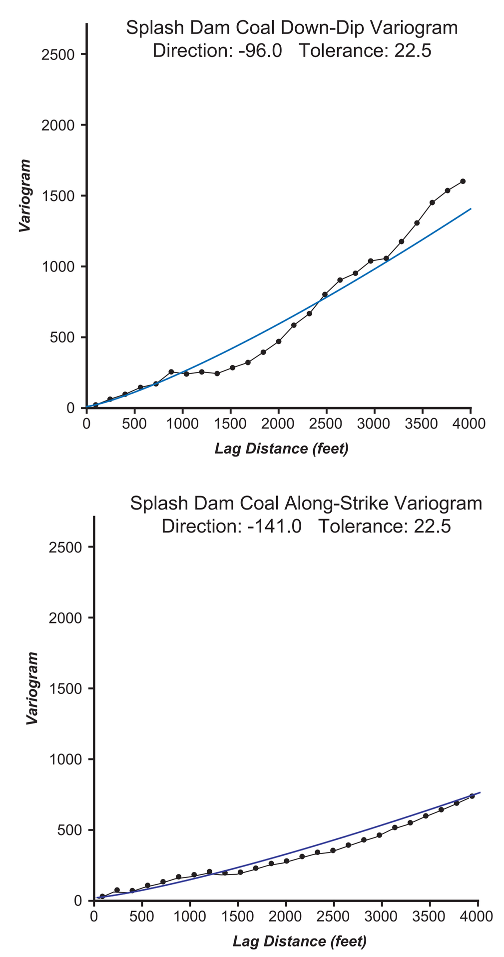


Figure 6. The variograms shown above for the Splash Dam coal bed in Harman 7.5-minute quadrangle of Buchanan County, are examples of power model variograms. The points represent the average variogram value for a given lag distance.

GENERATING ISOPACH MAPS

Thickness points were captured using Coal Point. The thickness points bounded by the red box, were exported to Surfer 8 to create the coal isopach map (Figures 7, 8, 9, and 10). The kriging method was used to generate the grids. According to the generated coal isopach maps for our study area, thickness in the Splash Dam coal bed ranges from approximately 30 to 73 inches, with a mean value of 48.4 inches and a standard deviation of 8.2. This thickness range is further supported by published geological information about the Harman quadrangle which notes an average Splash Dam coal bed thickness of 55.2 inches for the Harman and Jamboree quadrangles (Henika 1989).

COAL BED SURFACES

Contour maps are created from the elevation data points collected from mine maps, geologic maps, and core holes (Figures 7 and 11). The kriging method was used to create a regularly spaced array of elevation values from the irregularly spaced input elevation data. Gridded elevation data can then be used to create a three-dimensional structural surface for the coal bed (Figure 12).

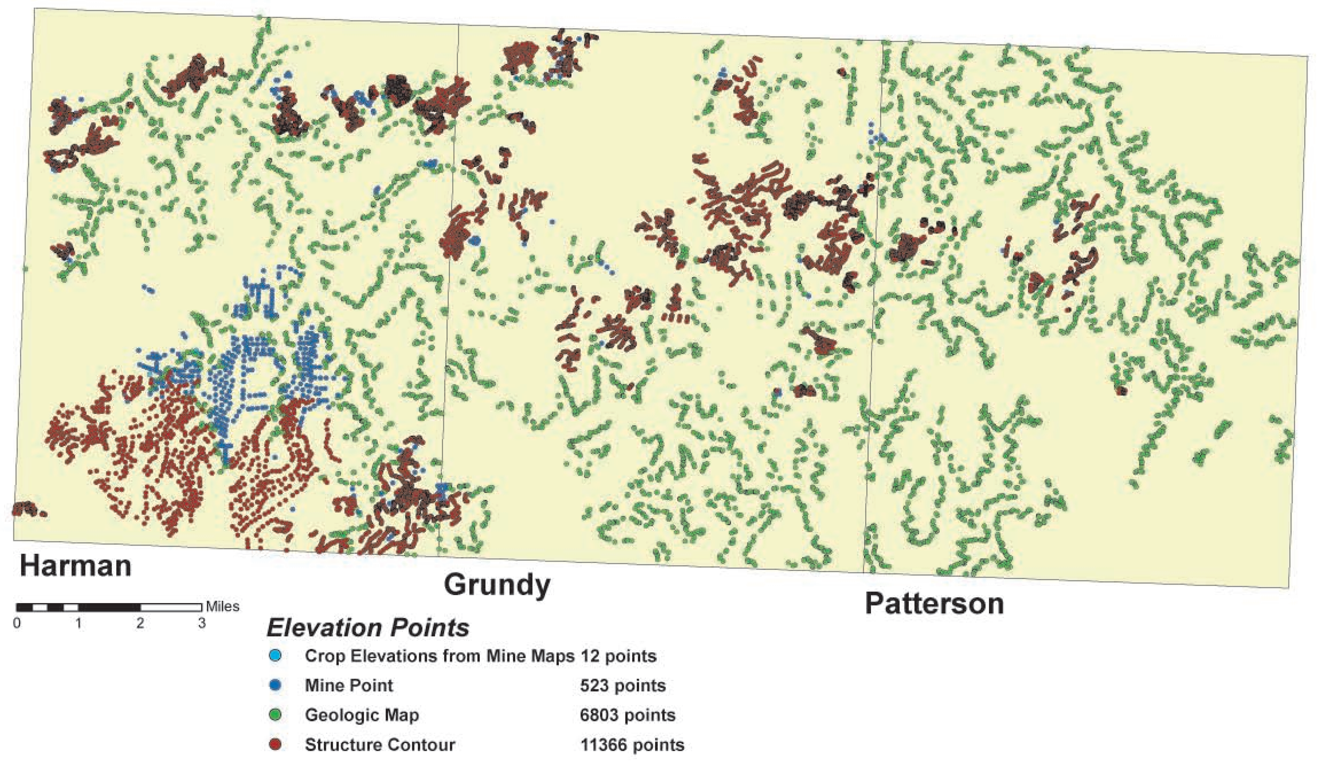


Figure 7. Elevation data points for the Splash Dam coal bed in the Harman, Grundy, and Patterson quadrangles, Buchanan County. Data points were collected from mine maps, geologic maps, and core holes.

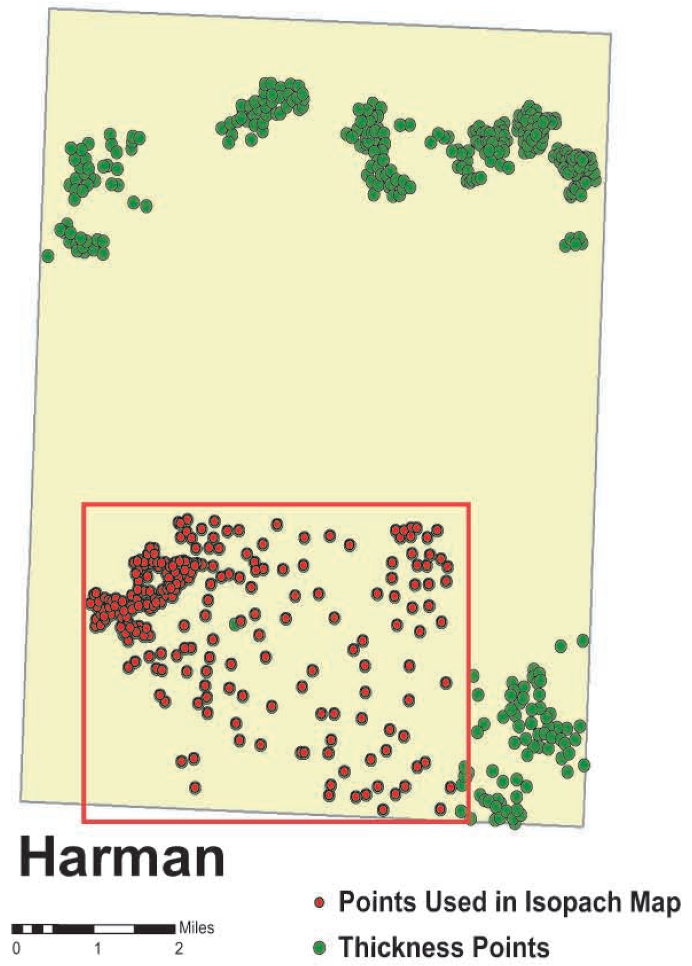


Figure 8. Thickness data points for the Splash Dam coal bed in Harman quadrangle. Data points were collected from mine maps and core holes.

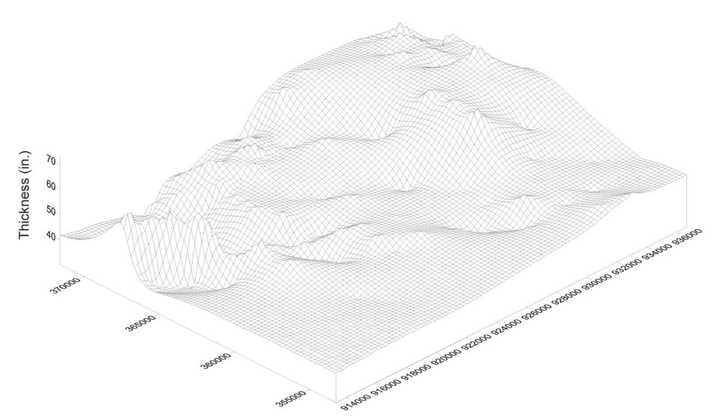


Figure 9. Wire diagram showing thickness of the Splash Dam coal bed generated using thickness points from the area bounded by the red box in Figure 8.

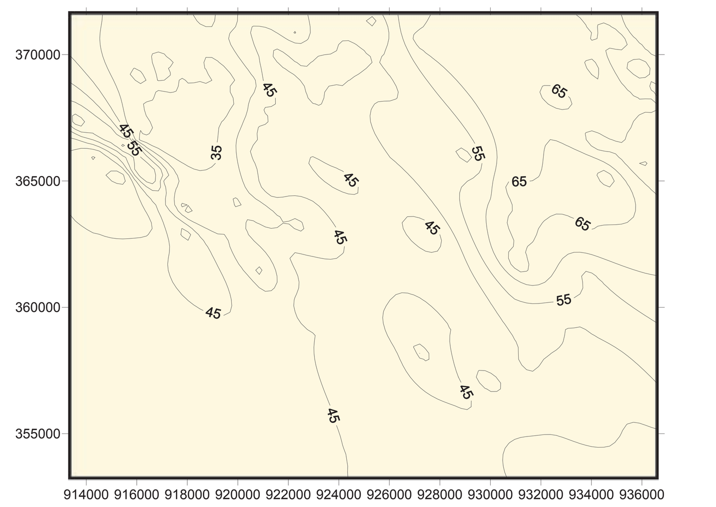


Figure 10. Five-inch-interval contoured coal isopach map generated using thickness points from the selected area. Coordinates in Virginia State Plane South NAD27 (feet).

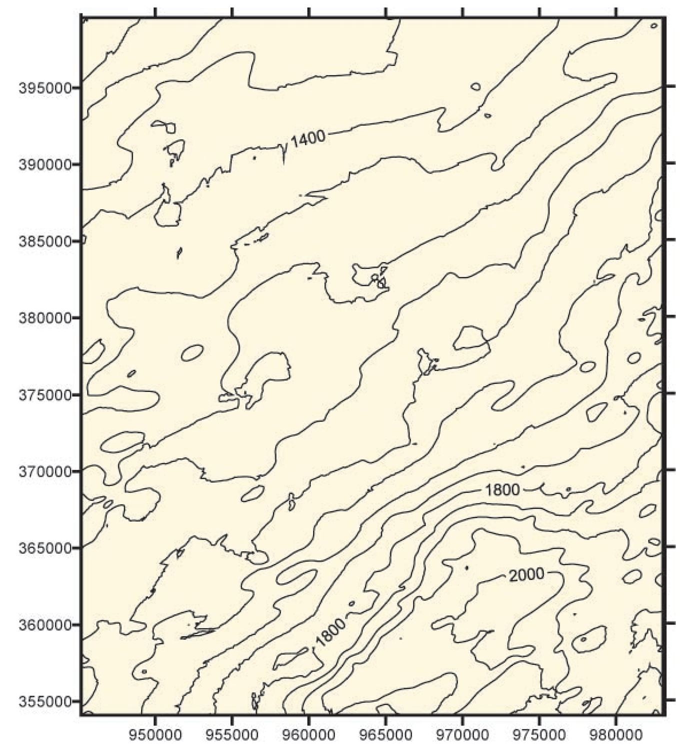


Figure 11. Structure contours for the Splash Dam coal bed in Grundy quadrangle, Buchanan County, Virginia. Coordinates in Virginia State Plane South NAD27 (feet).

CHALLENGES AND GOALS

Stratigraphic names

- Numerous stratigraphic names have been applied to the same coal bed both temporally and geographically. Jim Lovett of the Division Mineral Resources has worked to sort through and correlate these various coal bed names.

Data characteristics

- By relying heavily on individual mine maps as sources for elevation and thickness information, there is a level of uncertainty as to the accuracy of each map.
- Data is in many different formats and media types, creating compatibility issues.
- The fact that thickness data is clustered around mines means there is a lack of continuous thickness information available for generating isopach maps.

Scale

- The geological maps of the area have a scale of 1”=2,000’, while most of the mine maps have a scale of 1”=100’ to 1”=400’. This factor makes it difficult to determine the level of accuracy.

Additional data

- Additional core-hole data and geophysical information would be very useful, especially in areas where no mine map data exists.
- The next step for this project is to incorporate additional data from the rest of the coalfields.

ACKNOWLEDGEMENTS

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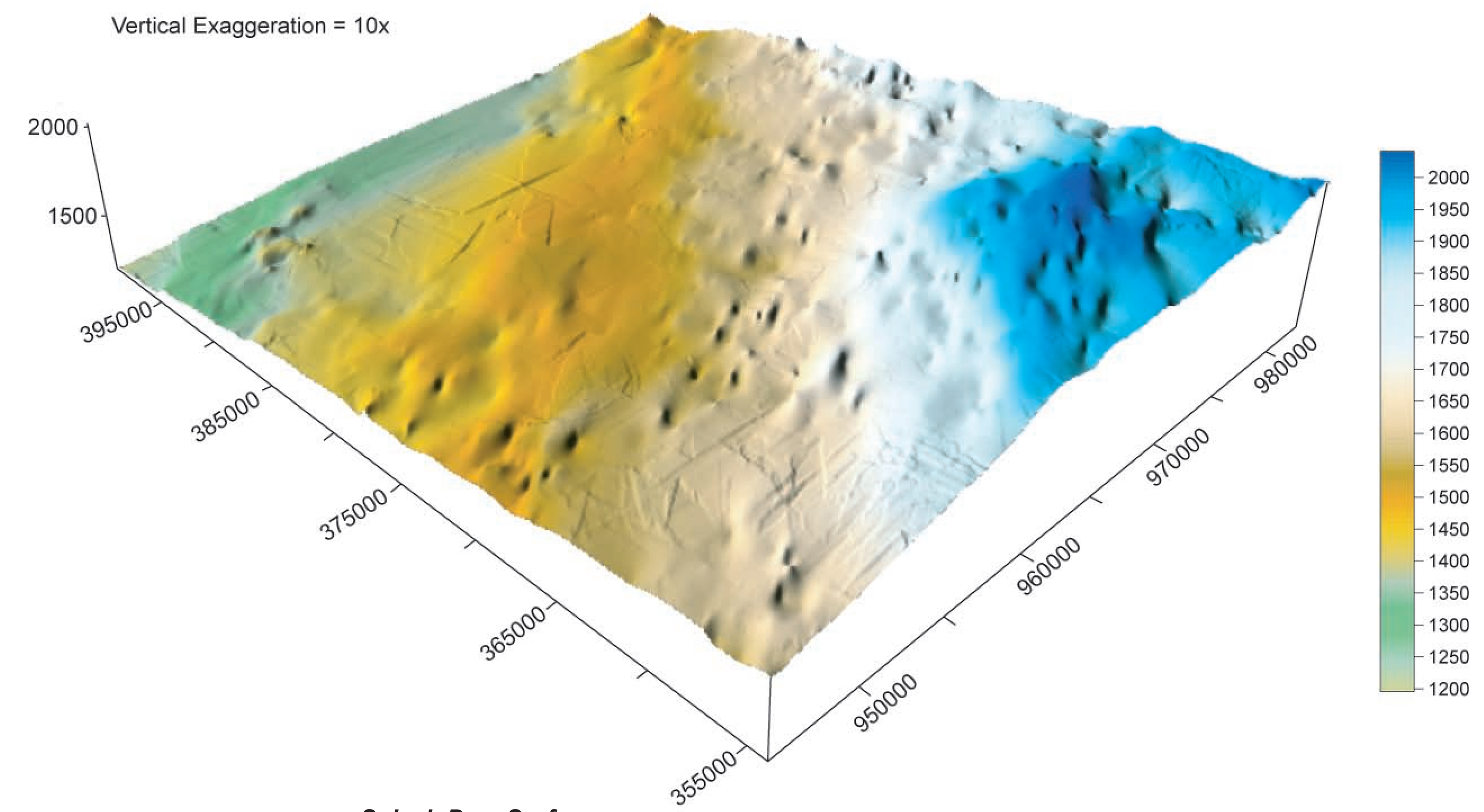
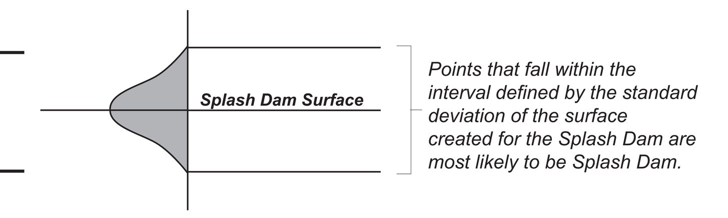


Splash Dam Surface
Kriging Estimation of Error (feet)

Mean Error	12.8
Minimum Error	3.6
Maximum Error	38.6
Standard Deviation	6.8



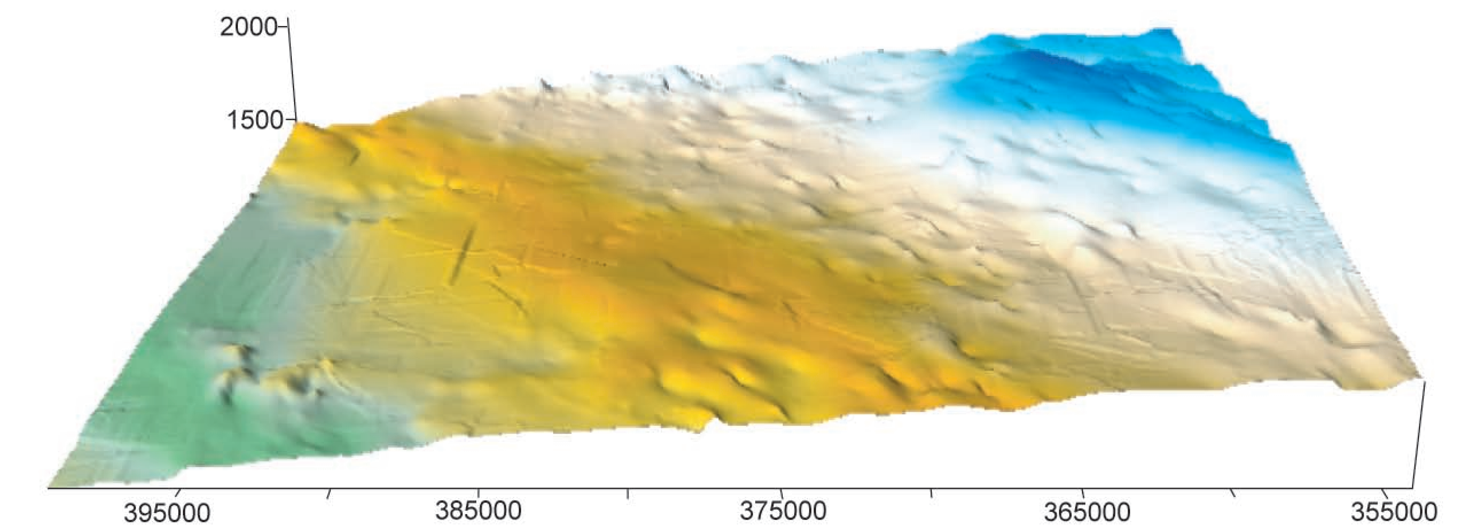


Figure 12. These three-dimensional surfaces for the Splash Dam coal bed in Grundy quadrangle were created in Surfer 8 using the kriging gridding method outlined in the Geostatistics section. Coordinates in Virginia State Plane South NAD27 (feet).

STACKED COAL BED SURFACES

By overlaying the Clintwood coal bed surface over the Splash Dam coal bed surface, the Middlesboro syncline and Pine Moutnain anticline as mapped by Henika (1989) are visible (Figure 13). Additional surfaces can be stacked, but for the purpose of illustration only two are shown here.

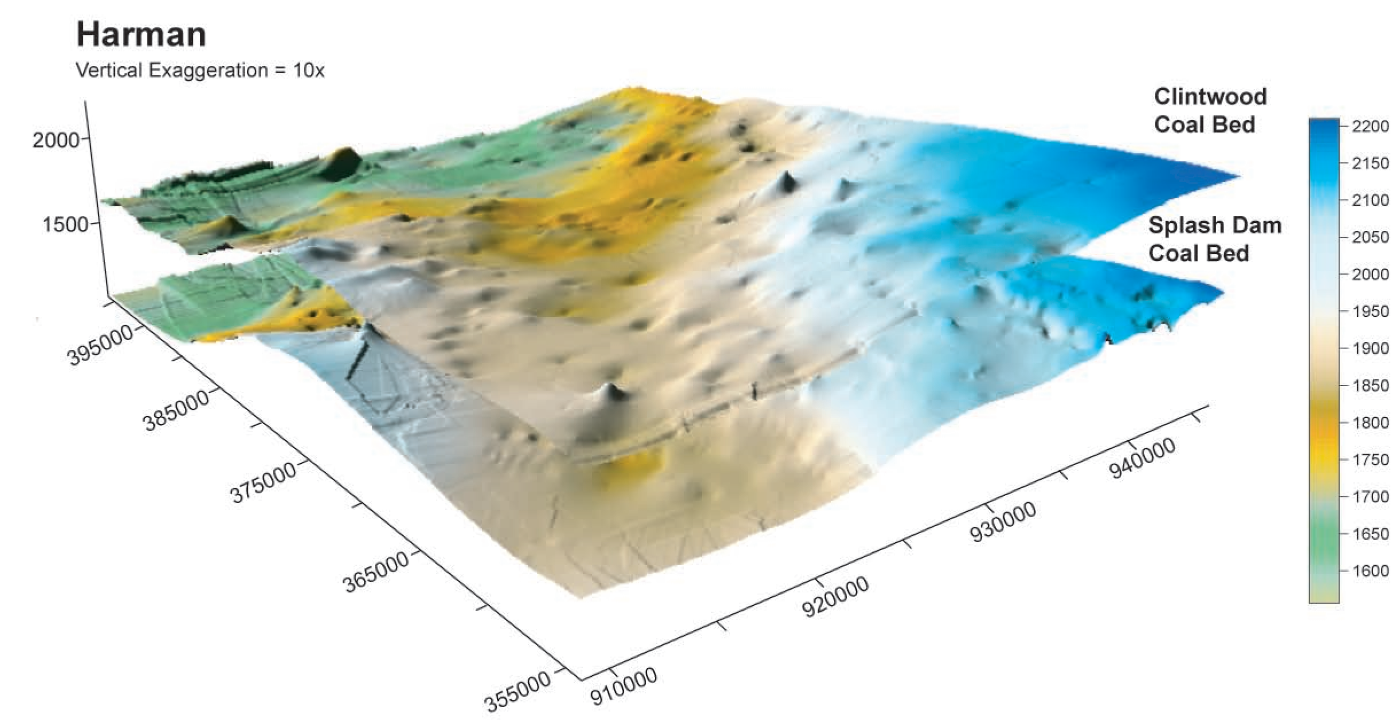


Figure 13. Using Surfer 8, coal bed surfaces can be stacked as the Splash Dam and Clintwood coal surfaces in the Harman quadrangle. Coordinates in Virginia State Plane South NAD27 (feet).

CONCLUSIONS

The Buchanan County coal modeling process shows how coal mine maps and geologic maps can be used to better understand how the structure and thickness of a coal bed varies on a small scale. Applying this information across areas that have been mined out will increase the accuracy of the model as it predicts the structure and thickness of a coal bed across remaining unmined areas. This model can therefore enable better estimates of remaining coal resources.

REFERENCES

Henika, W.S., 1989, Geology of the Virginia portion of the Harmon and Jamboree quadrangles: Virginia Division of Mineral Resources Publication 98.
Nolde, J.E., 1994, Devonian to Pennsylvanian stratigraphy and coal beds of the Appalachian Plateaus province: Virginia Division of Mineral Resources Publication 131.